THEORETICAL ANALYSES ON "SPLASH" FORMATION OF COMPETITIVE DIVING

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Based upon our work in theoretical analysis and computer simulation of the impact process between diver and water, the purpose of this study was to analyze mechanisms of "splash" formation. The entry technique with palms facing each other was simplified as water entry of a "wedged" object. The entry technique with internal rotation of the arms to form a flat impact surface with the palms was simplified as water entry of a "rectangle". Finally, the water entry with rotation was treated as water entry of a "rotating rectangle". Further mechanical analyses were performed to synthesize "splash" formation mechanisms of these different objects under various impact conditions, and formulate a splash control theory that combines an active impact and a "massaging" motion of water by both hands.

KEY WORDS: wedge, rectangle, impact between water and object, rip entry

INTRODUCTION: Splash control is a key element for water entry in competitive diving. From the entry till total submerge of the entire body under water, the size of water splash may directly influence the outcome of a competition. Therefore, it has become a focal point of both practical and theoretical interests as to how to minimize the splash size by using various body positions and entry techniques. Through trials and errors, coaches and divers have already accumulated some practical experiences and methods for the "splash control" technique. However, no breakthrough research has been performed on the theoretical basis of the technique; many aspects of the technique such as mechanisms of splash formation and optimization of splash control technique deserve further study.

METHODS: In order to examine the relationship between the hand pattern and the water splash height, the water was simplified as an ideal fluid and the human body as a wedge-shaped object during computer simulation

The entry technique with full extension of shoulders and palms facing each other was simplified as water entry of a "wedged" object. The entry technique with full extension of shoulders and internal rotation of the arms to form a flat impact surface with the palms was simplified as water entry of a "rectangle". Finally, the water entry with rotation was treated as water entry of a "rotating rectangle". Further mechanical analyses were performed to synthesize "splash" formation mechanisms of these different objects under various impact conditions, and formulate a splash control theory that combines an active impact and a "massaging" motion of water by both hands.

In addition, the application of the theory was carried out in training practice of Jiangshu diving team.

RESULTS: The human body was simplified as a wedged-shaped solid object and the water entry of the diver during the impact was treated as the impact between the wedged object and the water. According to the conservation of mass and energy, principle of momentum, and the principle of fluid viscosity, equations of continuity, motion (momentum equations), energy and constitutive equations can be derived These equations and basic equation sets of fluid dynamics are formulated in the forms of differential equations.

The equations have an infinite number of solutions. However, only those solutions satisfying boundary and initial conditions are meaningful. Therefore, the equations could be solved under certain boundary and initial conditions.

Computational software (FORTRAN) was developed using a finite element method to simulate the impact process of the wedged object with the ideal fluid; the comparisons were made from the results of computations with the wedge angle changed from 4° to 80°.
The results indicated that the highest point of the unrestrained wave surface after the impact increased with an increase in the wedge angle (slope). The greatest (sharpest) wedge angle elicited the highest water splash during the impact. The splash height changes by a factor of nearly 20 between 80 ° and 4 ° wedge angles (Qian, Zhang & Jin, 2001).

DISCUSSION: Why the sharpest wedge angle could elicit the greatest water splash during the impact? The explanation is that a part of impact energy is transferred to the fluid, which causes motion of the fluid and formation of splash. However, the splash formation is related to many different factors.
First the splash formation is related to fluid characteristics. Water as a special form of fluid has following unique features. (1) Incompressibility: Water can be only moved but not compressed during impact with rigid body. (2) Small adhesiveness: water motion displays non-uniformity under force application. Parts of water may move in directions other than the direction of the force. (3) Under compression, water tends to move in a direction whereas least pressure is present (most escapable). According these characteristics, motion characteristics of water during impact can be analyzed. In addition, the splash is related to the shape of the impact object.
Analysis of wedge impacting water surface: When the wedged object impacts the water with its sharp edge, water is compressed slantwise downward. The direction of the force is perpendicular to the inclined surface (Figure 1). The water closest to the wedge should move in the direction of the force application under the compression. Due to reaction forces from the surrounding water, its intended motion is restrained and forced to move along the wall of the sharp wedge upwards, i.e. in the most escapable direction.
The first impacted water will escape in the direction first. As the wedge continues to penetrate into water, the fluid at the top has already escaped along the wall; its location becomes the most escapable direction for the water below. Therefore, the underneath water continues to escape along this direction and forms the water splash. The greater the impact is, the higher the speed and thus the splash.

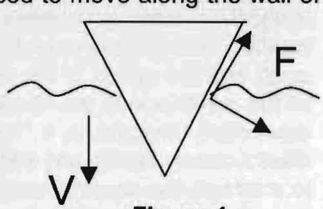

Figure 1

Even though the water escapes upwards along the slope of the wedge surfaces and forms splash, the splash height is determined by the oblique angle of the wedge wall, which is the project angle of the splash. The splash height increases with increased projection angle when the escape velocity is held constant. This is also verified in our computer simulation.
Analysis of the impact between a squared object and water: When the penetrating object is not wedged-shaped but rectangle shaped, the results of the impact are different. After the object submerges into water, the pressure is applied vertically downward. The water, under such pressure, disperses circumferentially. It does not form a most escapable direction due to the reaction forces from the surrounding water. Under such reaction forces (pressure) parts of water may move upwards along the vertical wall of the object (Figure 2). At the same time, however, the impacting object is moving downwards bringing its surrounding water with it because of high impact velocity. When such a velocity is greater than that for the velocity of the water traveling upwards along the wall, no apparent water splash is formed. Therefore, instead of having palms facing each other to form a wedge at the water entry, the diver can internally rotate the arms and form the impact surface with the palms towards the water to effectively limit the water splash. Nonetheless, the diver does not perform only simple vertical movements but also high-speed rotations and somersaults.

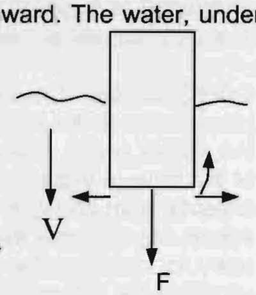

Figure 2

Analysis of Squared Object in Rotation and Somersault: When an object impacts water with high-speed rotation and somersault, its velocity's direction is not purely downward and is actually determined by the translational (V_v) and rotational (ω) velocities of the object with the resultant velocity (V) directing slantwise downward at the time of impact (Figure 3). If the diver were to impact the water with the flat palms after the initial entry, the squared object would move in the direction towards one of the conner. The water would escape along the surface of the palms and the sides of the arms resulting in the same "wedge" effect; the diver would fail to contain the splash, i.e. the splash would "float" away. At this time, the diver should rotate the wrist and hand in a direction opposite to the water resultant velocity. Once the diver contacts the water, the resistance from the water can create a resistive torque that has a direction just opposite to the angular motion of the body, cause a dramatic decrease of the angular velocity, ω, and produce a vertically downward direction for the resultant velocity of the water. At this time, the palms need to be turned downwards and maintain in a direction just opposite to the water's resultant velocity.

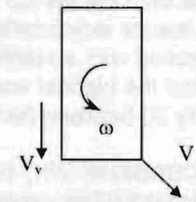

Figure 3

Therefore, when the diver enters water with either forward or backward somersault, the direction of the body's velocity at the instance is not vertically downward but slantwise downward. At this time, the diver should adopt certain technique to maintain the palms in a position perpendicular to the water's velocity. In the forward somersault, the diver should push downward with the base of palms and the little finger's side and keep the palm facing anteriorly downward at the water entry. In a dive with the backward somersaults, the diver should to push downward with the side of the thumbs and keep the palms facing posteriorly downward instead. Once the diver contacts the water, the reaction force from the water instantly creates a resistive torque that is applied in a direction just opposite to the body rotation, and dramatically reduces the speed of the body's rotation. At this time, it is critical to push with the palms in the opposite direction to keep the palms perpendicular to the direction of the water speed as discussed previously in order to rotate the palms towards a vertically downward direction in a "massaging" motion. In order to effectively control the splash, the diver not only flexes and internally rotates the shoulder joints and pushes the palms outwards to maintain the squared shape for water entry, but also "massages" the water successfully.

Based upon the results from computer modeling and simulation of "rip entry" between solid objects and fluid and investigation of splash formation mechanisms, it was proposed to actively impact and "massage" water with both hands during water entry to effectively control the splash. Using a double blind method, an experimental training study was performed on divers (n = 13) of the Jiangshu diving team in a period of two months. Successful rates before and after the training experiments were evaluated with statistical procedures to demonstrate the training effect utilizing theory and method of the active water impact and "massaging". The results showed that the participating divers gained an earlier establishment of "feeling of touching water", a shortened learning period of the splash control technique, and an improved successful rate (from 70.0% to 81.5%).

CONCLUSION: The simulation results indicated that the slope of the wedge was inversely proportional to the impact magnitude and the decline of the body velocity, but proportional to the splash height. The splash height is also closely related to the hand pattern used in diving at the time of impact. Using a technique with an internally rotated and fully flexed (straight) shoulder joint and both hands forming a "squared" surface, a diver can effectively reduce the splash but increase the risk of injury. It is imperative to "massage" the water after the initial entry to maintain the palms opposite to the direction of the water velocity to effectively minimize the splash according to the direction and speed of the body rotation.

REFERENCES:

Qian, Jingguang, Zhang, Songning, Jin, Haiquan. (2001). Computer Simulation of "Splash Control" in Competitive Diving, *Proceedings of Swim Sessions, XIX International symposium on Biomechanics in Sports.* pp 113-116.